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HCM - SOIL MOISTURE IN RELATION TO GEOLOGIC STRUCTURES AND
LITHOLOGY, NORTHERN CALIFORNIA

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16. Abstract <p>HCMM images of about 80,000 km² in northern California were qualitatively evaluated for usefulness in regional geologic investigations of structure and lithology. The thermal characteristics recorded varies among the several geomorphic provinces and depends chiefly on the topographic expression and vegetation cover. Identification of rock types, or groups of rock types, was most successfully carried out within the semi-arid parts of the region; however, extensive features, such as faults, folds and volcanic fields could be delineated. Comparisons of seasonally obtained HCMM images were of limited value, except in semi-arid regions.</p>			
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PREFACE

- (a) Objectives: The objectives of the project were to qualitatively assess the value of the HCMM thermal imagery as applied to regional geologic interpretation of structures and lithologies in northern California. The study was based on the probable seasonal soil moisture changes as a function of the bedrock type. An additional objective was to delineate known geothermal areas in the region.
- (b) Scope of the Work: HCMM images were reviewed in an attempt to relate recognizable thermal characteristics with known geologic features and to compare the data with published geologic maps.
- (c) Conclusions: The regional geologic analysis has demonstrated that the interpretability of the HCMM images for geologic purposes is overwhelmingly influenced by surface topography and vegetation cover; but the images might be most useful in arid or semi-arid regions where the underlying rocks are not masked by thick soil or vegetation.
- (d) Recommendations: Future work should concentrate on the improvement in the scale and resolution of the images and to improve the quality of the products furnished.

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INTRODUCTION

The objectives of the project were to qualitatively assess the value of the HCMM thermal imagery in regional geologic interpretation. The study focused on the thermal characteristics of geologic structures and lithologies, the significance of, and changes in, the natural soil moisture as it might be related to the underlying geology and to determine the thermal signature (if any) of known geothermal areas.

The study area includes all of northern California. It extends from the Oregon-California border (Latitude $42^{\circ}00'N$) to the vicinity of San Francisco Bay (Latitude $38^{\circ}00'N$) and from the Pacific Ocean to the crest of the Sierra Nevada (longitude $120^{\circ}00'W$), an area of about $130,000 \text{ km}^2$ ($50,000 \text{ mi.}^2$).

The region contains a diversity of geologic structures, lithologies, and landforms. The geologic structure is extremely complex and is not thoroughly understood. Recent ideas on plate tectonics attribute the structural complexity of much of the region to deformation along subduction zones associated with late Mesozoic Trenches. Further complexity has been superimposed by transform movement along the San Andreas Fault zone. Rock types are extremely varied and include peridotite, serpentinite, metasedimentary rock, and sedimentary rock of all types in the Coast Ranges; uniformly bedded Mesozoic clastic sedimentary rock and Pleistocene to Holocene alluvial fill in the Sacramento Valley; granitic plutons and infolded metamorphic rocks in the Sierra Nevada; and extrusive volcanic rocks with varying composition in the Modoc Plateau. Each of these areas displays geomorphic features that are characteristic of the region and of the underlying rock types or structure.

Photogeologic examination of the thermal images of an area so large and geologically diverse is a formidable task. The decision was made early in the investigation that a detailed analysis of each of the more than 500 image frames would be unrealistic but that a thorough examination for regionally significant geologic features would provide a firm base for gleaning maximum detail from each image.

METHOD OF STUDY

Data available;

1. Two copies each of Day visible, Day IR, and Nite IR, 241 mm positive transparencies and one copy each of positive paper prints were requested on the original contract and were received. About 500 individual images were received of which less than 10% were of usable quality. Excessive cloud- and fog- cover on many of the images, particularly the nite IR, was the chief limiting factor for usefulness in geologic interpretation. The photographic quality of the HCMM images varied considerably in graytone characteristics so that it was possible to make only crude comparisons between images taken from successive orbital-passes over the area or between passes taken at different times of the year. The earliest images available were from the spring of 1978 near the end of a two-year drought in California; hence, these images may not reflect the thermal characteristics representative of those taken during normal weather conditions. Among the various types of images, the Day visible and Nite IR proved to be the most useful for lithologic, structural, and drainage analysis. Data requests for

Thermal Difference and Apparent Thermal Inertia products of representative seasons in the project area were retrospectively ordered and subsequently received. These images yielded only a limited amount of additional geologic information; but, in a general way, confirmed interpretations deduced from the Day and Nite IR images.

2. NASA Aircraft Underflight During the pre-launch stage, the project utilized previously obtained (1973) NASA Aircraft IR photography. These photos were of a 30 - 40 mile wide east-west test strip centered along the 39°00' parallel in northern California and covered only a small part of the area. The photographs from these underflight were examined in detail during the pre-launch period in order to establish possible criteria for the various lithologic and structural details within the various microclimatic regions. During the course of the project, comparison of the HCMM images with the underflight photography was used extensively, where appropriate.
3. Landsat-1 imagery was available for the entire region and was used extensively for pinpointing recognizable vegetation changes and as a check on specific geologic features or characteristics observed on the HCMM imagery.

Equipment:

The equipment used to examine the HCMM images was of the simplest type. In addition to the usual photo interpretive equipment, such as light tables and binocular microscope, the images were projected onto a translucent frosted glass screen mounted in a movable frame. The projector was a standard 'over-the-counter' type 3 1/4" x 4 1/4" classroom lantern slide projector. The area to be studied was cut from one copy of the positive transparencies and

mounted between glass plates. A second copy of the image was filed for reference purposes.

The images could be effectively enlarged to a scale of about 1:500,000; however, because of the loss of resolution at this scale, a working scale of 1:1,000,000 was established. The images were scale-adjusted by projection onto a 1:1,000,000 topographic map of California.

Correlation of Geologic Data:

The Principal Investigator has geologically mapped part of the project area, and he has basic geologic familiarity with other parts. For the regions less familiar to the Principal Investigator, the information obtained from the HCMM images was carefully compared with published geologic maps and with Landsat images.

SCIENTIFIC RESULTS

Introduction:

The predominant geologic and topographic trend in northern California is north-northwest (Figure 1) and it is apparent that this trend effects the regional thermal characteristics as depicted on the HCMM imagery. Superimposed on the general trend are several distinct geomorphic provinces (Figure 2); each province exhibits a unique topographic expression and unique microclimatic characteristics. The principle terrestrial influence on the thermal characteristics observed on the HCMM imagery was found to be topography. The diurnal thermal variations interact with a given topographic regime to produce the local microclimatic effects most readily observed on the HCMM imagery. The more subtle thermal effects due to structure, lithology and soil moisture could be recognized only with difficulty after the effects of topography had been determined and taken into account. Consequently, each of the several geomorphic provinces (Figure 2) were analysed separately.

Figures 3 and 4 are Nite IR and Day IR images obtained on May 30 and May 31, respectively, and Figures 5 and 6 were obtained on October 5 and October 6, 1978 respectively. These images will be referred to throughout the remainder of this report.

Northern Coast Ranges:

The present land surface in the Northern Coast Range varies in elevation from sea level along the coast to a maximum of about 2600 meters at the crest of

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Figure 1 Landsat Mosaic of Northern California

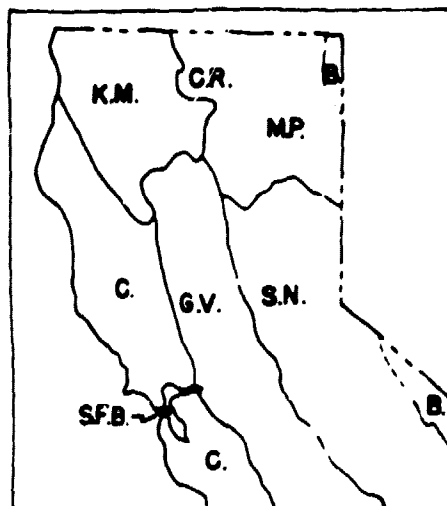


FIGURE 2. PHYSIOGRAPHIC PROVINCES IN NORTHERN CALIFORNIA. K.M.-Klamath Mountains; C.-Coast Ranges; G.V.-Great Valley; C.R.-Cascade Ranges; M.P.-Modoc Plateau; S.N.-Sierra Nevada; B.-Basin and Range (from Thornbury, 1965); S.F.B.-San Francisco Bay.

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Figure 3 HCMM, Nite IR, May 30, 1978, # A-A0034-10201-3
SAF-San Anreeas Fault; L-Lineations; CM-Chico
Monocline

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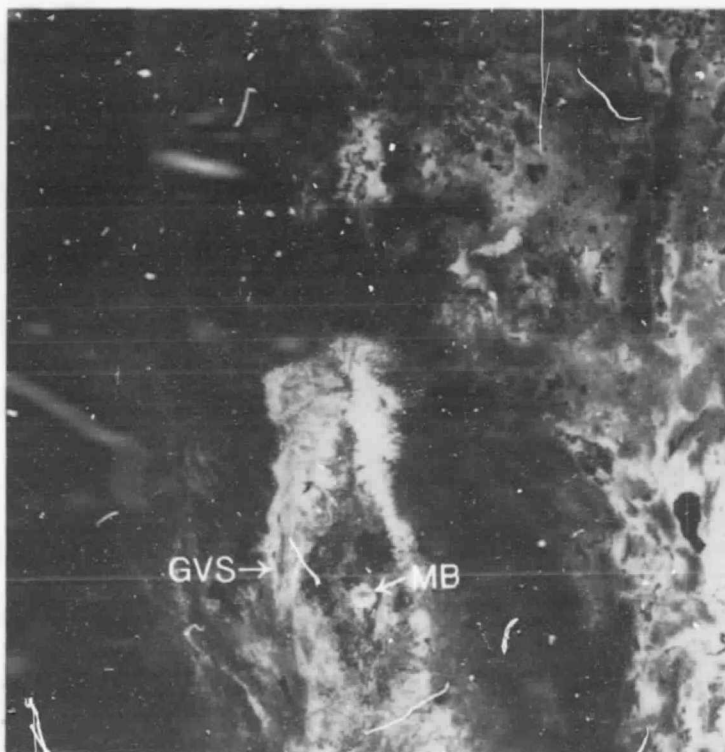


Figure 4 HCMM, Day IR, May 31, 1978, # A-A0035-2133C-2
GVS-Great Valley Sequence; MB-Marysville Butte

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Figure 5 HCMM, Nite IR, October 5, 1978, # A-A0162-10040-3
L-Lineations; GVS-Great Valley Sequence; AF-
Alluvial Fans; CM-Chico Monocline; V-Volcanoes

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Figure 6 HCMM, Day IR, October 6, 1978, # A-A0163-21160-2

the range and decreases to an elevation of about 300 meters along the eastern slope. The annual precipitation ranges from about 100 cm along the coast to about 80 cm near the crest and to about 50 cm along the leeward (eastern) side of the range. In general, the kind and amount of vegetation changes with elevation and precipitation. Along the coast, the vegetation consists chiefly of dense redwood and conifer forests, with localized interspersed brush and grasslands. On the western slopes, the vegetation changes to conifer forests (chiefly pine) and these forests constitute the bulk of the vegetation within the Northern Coast Range. Brush and scrub oak predominate on the leeward slope.

The geology of the Coast Range is complex. The rocks are commonly covered by a thick soil under a canopy of vegetation, thus bedrock exposures are rare. The thermal characteristics in this area are influenced chiefly by topography and vegetation, and the influence of exposed lithologies upon the thermal spectrum is limited. A few geologic features are nevertheless discernable on the Nite IR images.

The bedrock in the Coast Range consists chiefly of metasedimentary and sedimentary rocks of Mesozoic age that locally have been intruded by serpentinite. In some area, the Mesozoic rocks are overlain by Tertiary volcanic flows. All of these rocks have undergone structurally complex deformation and represent the melange belt along the Pacific Coast. The principal structural elements are northwest-trending faults and fractures, subparallel with the present trend of the San Andreas Fault ("SAF" Figure 3).

Attempts to segregate specific rock types, or groups of related rock types, on the HCM images were largely unsuccessful; however, lineations related to the northwest-trending faults and fractures are clearly discernable ("L" on Figures 3 and 5). On some images the San Andreas Fault ("SAF" on Figure 3) is clearly

displayed. Inasmuch as the lineations and the San Andreas Fault coincide with known topographic troughs occupied by modern streams, it is thought that the tonal representation on the HCMM images is more directly related to topography, stream-associated soil moisture or diurnal thermal layering than to any unique thermal properties related to the faults. Analysis of the HCMM images taken at various times of the year did not disclose any specific thermal characteristics that might be related directly to rock types or structural elements.

The Northern Coast Range contains one of the world's largest producing geothermal fields--the Geysers--and many well-known hot spring areas. Nevertheless, no evidence of these geothermal areas could be detected on any of the HCMM images that were received by the project, regardless of the time of year the images were obtained.

In summary, the ability to detect differences in rock types or geothermal areas within the Northern Coast Range is of extremely limited value. Although some linear elements could be detected, it was thought that these lineaments are more directly related to the topographic and vegetative effects on the imagery than to any inherent direct thermal properties related to structure or to rock type.

Sacramento Valley:

The land surface within the Sacramento Valley (Figures 1 and 2) ranges in elevation from 350 meters above sealevel around the margins of the Valley to about 30 meters near the axis of the Valley. The annual precipitation ranges from 40 to 50 cm and the area is commonly classified as semiarid. The vegetation along the margins of the Sacramento Valley consists of grasslands with some localized areas dominated by scrub oak and/or dense brush. The

central part of the Valley is irrigated and intensely cultivated.

A ridge and valley topography, developed on the homoclinally dipping interbeds of marine sandstone and shale of Mesozoic age, dominates the southwestern margin of the Valley ("GVS" on Figures 4 and 5). In contrast, the topography along the northwestern margin is represented by a gently east-dipping surface developed on late Tertiary to Recent alluvial fans ("AF" on Figure 5). The central part of the Valley is a relatively smooth south-sloping surface underlain by thick alluvial material deposited by the Sacramento River during Pleistocene to Recent time. The eastern margin of the Valley is defined by the trend of the Chico Monocline ("CM" on Figure 5) and the land surface rises gently eastward from the monoclinial axis. East of the monocline, the topography is a relatively smooth west-sloping surface into which deep canyons have been incised, and locally, the Mesozoic rocks are exposed in the bottoms of the streams. The bedrock across the monocline consists of interbedded basaltic- to andesitic-lava flows, pyroclastic and lahars (volcanic mudflows).

Within the region of ridge and valley topography along the southwestern margin of the Valley ("GVS" on Figures 4 and 5), the massive sandstone beds that underlie the ridges can be clearly delineated from the intervening shale beds that underlie the valleys on some of the images; but, in general, this can be seen best on images taken during the spring growing season. Analyses of several images taken during this time period suggest that the different soil moisture conditions between the more porous sandstone beds and the less permeable shale beds may account for some of the tonal differences observed on the HCMM imagery; however, these effects are not easily separated from the tonal differences arising due to topographic expression. Depending on the quality of the image reproduction, the weather conditions prevailing at the time the image was

obtained and the previous weather history, the certainty of interpretation was seriously affected.

Subtle tonal differences were observed on the alluvial fans ("AF" on Figure 5) that border the northwestern margin of the Valley. When compared with the geologic maps of the area, these tonal differences appear to be related to the two episodes of alluvial fan development in that area. The older fans (Plio-Pleistocene in age) appear to exhibit a graytone slightly darker (cooler) than that observed on the recently building fans. These tonal differences were more pronounced on the Nite IR images taken during the late summer or early autumn (Figure 5). Inasmuch as no obvious difference in vegetation or in topography exist between the two generations of fan development, the tonal difference is attributed to retained soil moisture, although no direct soil moisture measurements were made in the field. The older fan material is more indurated and probably retains more moisture throughout the summer than does the relatively loosely compacted sand and gravel on the more recent alluvial fans. Again, no consistency of this phenomenon could be observed on all HCMM imagery, even within a few days time span.

Along the northeastern margin of the Sacramento Valley, the axis of the Chico Monocline ("CM" on Figures 3 and 5) is defined on many of the Nite IR images as a sharp linear tonal change from medium- to light-gray tonal value west of the axis to very light-gray to white tones on the east. This tonal change may reflect subtle changes in the surface moisture resulting from the down-dip or down-slope migration of groundwater, released at the surface, along the many fractures at the crest of the monocline. Landsat images and air photos do not indicate any marked vegetation changes along the axis. Previous field investigations by the Principal Investigator during late summer months disclosed

that a distinct set of fractures exist along the axis and very locally they appear to be the loci of surface water seeps. This observation cannot adequately account for the continuous linear tonal change observed on the HCMM images because the seeps are too small and too localized to be expressed at the scale of the imagery.

No change in lithology is apparent on either limb of the monocline and this is substantiated by air photo and field observations. Further, no definitive thermal characteristics related to bedrock could be found on the HCMM imagery in adjacent areas that have not been effected by folding. The tonal change may reflect, to some extent, the abrupt change in topographic relief or to the angle of exposure of the west-facing slope, because the slope is relatively warmer during the day (Figure 4) and cooler at night (Figure 3 and 5). Thus, the linear feature seems to be related to a combination of factors - - soil moisture and topographic exposure.

One of the objectives of the project was the possible recognition of buried stream channels beneath the alluvial deposits within the central part of the Sacramento Valley. This objective was not successful; partly because the intensively irrigated ground masked any subtle natural moisture variations that might exist and partly because of the small scale and resolution of the images. An attempt was made to evaluate the thermal characteristics of the irrigation patterns to determine whether or not the various episodes of irrigation during the summer might be related to plant stress and hence possibly reflect subsurface moisture conditions. This investigation was unsuccessful.

A small igneous intrusion within the Sacramento Valley (Marysville Butte, "MB" on Figure 4), is clearly evident on some of the HCMM images. On a few images, for example, Figure 4, it was possible to differentiate the igneous core

(dark-gray tone) from the surrounding upturned Mesozoic and Tertiary sedimentary rocks. However, it was not possible to differentiate specific rock types within the sedimentary sequence nor to detect small faults that are known to transect the Butte. The igneous core of the Butte supports little vegetation so that bedrock exposures predominate; whereas the surrounding sedimentary rocks develop a thin soil veneer which supports a heavy growth of grasses. The thermal characteristics, therefore, may be related, in part, to the amount of vegetative cover.

To summarize, although geologic interpretation of HCMM imagery within the semiarid Sacramento Valley must be "filtered" through the thermal effects caused by topography and vegetation, the results of this investigation suggest that very useful qualitative geologic information can be obtained from the thermal images.

Modoc Plateau:

The land surface within the Modoc Plateau in northeastern California (Figure 2) ranges in elevation from about 350 m along the axis of the Chico Monocline to about 2500 m, with a maximum of about 3000 m at the top of the higher volcanic peaks. The vegetation consists chiefly of conifer forests with interspersed brushlands. In the higher elevations, the region receives about 100 cm of precipitation, mostly in the form of winter snow. The eastern and western margins of the plateau receives about 50 cm of precipitation.

The Modoc Plateau is made up of thick and widespread andesitic to basaltic lava flows, pyroclastic deposits and lahars of Pliocene age and volcanic cones of Plio-Pleistocene age. The most prominent volcano is Mt. Lassen which was last active in the late 1920's. The region contains several known hot spring

areas and, locally, broad geothermally warm areas. The region has undergone extensive glaciation during the Pleistocene and hence many of the landforms reflect glacial erosion during that period.

Attempts to differentiate the various lava flows on the HCMM images was generally unsuccessful; although, on some of the images, the outlines of flows (defined by thermal characteristics) were observed. The delineation of the flows from the HCMM images was extremely doubtful because the outlines of these flows changed from image to image or were not evident at all on most images.

On some of the Nite IR images ("V" on Figure 5) the larger volcanoes were clearly evident. The thermal characteristics consist of cool (dark) regions around the base of the volcanoes, a warmer (light) band around the flanks and a small circular cool (dark) zone at the crest. The vegetation on the volcanoes consists of uniformly dense conifer and brush near the base and along the flanks but brush predominates near the crest. Vegetation changes may account for the thermal characteristics observed on the images. However, the geologic relations suggest that debris accumulated at the base of the volcanoes, consists of clayey alluvial material which may retain more soil moisture than do the flanks of the volcanoes which are underlain by coherent vesicular volcanic rock. The small circular cool part at the crests of the volcanoes may represent small depressions which contain colluvial material washed from the sides of the depressions. Alternatively, since the warmer areas along the flanks of several of the volcanoes appears to be at about the same elevation in any single image (although the warmer area appears to move upward or downward, depending on the season of the year), the phenomena may be the result of atmospheric layering. Atmospheric layering was observed within many of the stream valleys along the western front of the Modoc Plateau and the Sierra Nevada and around the fringes

of many of the intermontaine basins in the Great Basin of Nevada. A similar atmospheric layering effect may explain the systematic thermal variations observed on the volcanoes of the Modoc Plateau.

Several geothermal areas are known to exist within the Modoc Plateau; however, definitive criteria for delineate these areas on the HCMM imagery were not observed.

The junction of the southern boundary of the Modoc Plateau and the northern boundary of the Sierra Nevada is geologically rather sharp and consists of the juxtaposition of volcanic rocks of the Plateau against the granitic plutonic and metamorphic rocks of the Sierra Nevada. The Sierra Nevada province is characterized by many deeply incised stream valleys that, in general, trend southwestward; whereas the Modoc Plateau is characterized by a deranged drainage pattern in the east-central part and by a fine-textured linear pattern along the western margin. On the basis of the observed thermal layering within the stream valleys on the Nite IR images, the junction of the two provinces could be deduced by the change in drainage patterns. This observation depends on the differences in topographic expression rather than on any thermal effects directly caused by different lithologic units or structure.

Summary:

The thermal IR characteristics of the HCMM images varies among the geomorphic provinces within Northern California and in some instances within a single province. Each province has a few specific features that can be delineated on the HCMM imagery. For example: 1) linear features representing faults or fracture zones may be recognized, and locally used to supplement current ground information, within the northern Coast Ranges; 2) thermal

characteristics along the margins of the Sacramento Valley, a semi-arid environment, can be directly related to the varying lithology and structural elements; and 3) volcanoes within the Modoc Plateau can be identified by their unusual thermal characteristics.

CONCLUSIONS

The results of this investigation can be summarized as follows:

1) Topographic expression and vegetation type and density appears to have the greatest influence on the thermal characteristics recorded on the HCMM images. These characteristics may give clues to the underlying bedrock and geologic structure, if used with extreme caution:

2) Seasonal variation in the thermal characteristics of geologic features, as reflected on the imagery, were not as useful for geologic interpretation as was anticipated. Either the weather condition (or history) at the critical times of the year was not appropriate or the quality of the imagery was uncertain. These qualifications can be a hindrance to the geologic interpretation of a region;

3) Evaluation of the images taken over semiarid regions in northern California suggest that, for geologic purposes, the HCMM imagery might be most useful for lithologic and structural studies of arid or semiarid regions where bedrock is not masked by thick soil or vegetation cover;

4) On none of the images could the extensive and well known geothermal areas within Northern California be recognized;

5) The scale and resolution of the imagery was not adequate for detailed geologic work but the images might be used, within appropriate limits, for areal reconnaissance on a regional scale to extract potential clues for more careful studies;

6) The thermal Difference and Apparent Thermal Inertia images provided to the project were of extremely limited value for qualitative geologic interpretations, although they tended to confirm interpretations made on the individual Day-Nite image.